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FRACTURE TOUGHNESS AND FATIGUE CRACK GROWTH PROPERTIES OF 7175-T736 ALUMINUM ALLOY FORGING AT SEVERAL TEMPERATURES

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R. E. JONES

UNIVERSITY OF DAYTON
RESEARCH INSTITUTE

TECHNICAL REPORT AFML-TR-72-1

FEBRUARY 1972

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AIR FORCE MATERIALS LABORATORY
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FOREWORD

This report was prepared by the University of Dayton Research Institute, Dayton, Ohio. The work was performed under USAF Contract No. F33615-71-C-1054. The contract was initiated under Project No. 7381, "Materials Applications," Task No. 738106, "Design Information Development," and administered by the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, Mr. David C. Watson (AFML/LAE), Project Engineer.

All (or many) of the items compared in this report were commercial items that were not developed or manufactured to meet Government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to me et the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

The author would like to acknowledge that testing performed for this program was accomplished by Messrs. R. J. Marton and J. H. Eblin. Engineering support was provided by Mr. G. J. Petrak.

The report covers work conducted from June 1970 to May 1971. The contractor's report number is UDRI-TR-71-46.

The report was submitted by the author in June 1971.

This technical report has been reviewed and is approved.

Albert Olevitch

A. OLEVITCH
Chief, Materials Engineering Branch
Materials Support Division
Air Force Materials Laboratory

ABSTRACT

Tensile, fracture toughness, and crack growth properties of 7175-T736 aluminum alloy die forging were investigated at various temperatures from -65°F to 350°F. Room temperature tensile and fracture toughness data was compared to similar properties for wrought 7075 products. The 7175 appears to be a better alloy. Fatigue crack growth rates at room temperature were similar to 7075-T6 and 7075-T7352 crack growth data in the literature. Crack growth rates increased with increasing temperature from room temperature to 350°F. Crack growth rates below room temperature were probably affected by condensation of moisture at the crack tip and results were inconsistent.

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SECTION I
INTRODUCTION

High strength aluminum alloys are continually being investigated by the aerospace industry so as to improve inservice aircraft components and to fabricate the latest high performance aircraft with available materials of optimum properties. Because of the improved toughness-tensile strength combination and excellent resistance to stress corrosion cracking in the -T736 condition, 7175 aluminum alloy die forgings are being considered for use in applications where 7075-T6 and 7075-T73 aluminum alloys are presently in use. A preliminary investigation by Petrak (Reference 1) has shown the 7175-T736 alloy to have superior fracture toughness and stress corrosion properties relative to 7075-T6. Data for 7175-T736 from Reference 1 are presented in the appendix. In this initial investigation both precracked compact tension specimens immersed constantly and smooth specimens alternately immersed were tested to determine the stress corrosion behavior. Based on the encouraging results from this investigation, it was decided to conduct a more comprehensive test program. Consequently, a section of a forging was procured from the Aluminum Company of America (ALCOA) by the University of Dayton Research Institute under Air Force Contract F33615-71-C-1054 in order to study tensile, fracture toughness, and fatigue crack growth properties at several temperatures. The linear elastic fracture mechanics approach to fatigue crack growth analysis and presentation was utilized.

SECTION II

MATERIAL AND SPECIMENS

A 31-inch long section of a 7175-T736 bar forging with varying cross-sectional shape (see Figure 1) was received from ALCOA. The average cross-section was approximately 2-1/2 inches x 2-1/2 inches. The 7175 alloy has essentially the same chemical composition as 7075 with the exception of lower iron and silicon content. Thermal processing of this alloy is a proprietary process of the manufacturer.

Tensile and fracture toughness properties were investigated using the specimen configurations shown in Figures 2 and 3, respectively. Both tensile and compact tension fracture toughness specimens were removed in the longitudinal, transverse, and short transverse grain directions. Compact tension specimens were machined to three different thicknesses (see Figure 3).

Fatigue crack growth properties were studied utilizing the 3/4-inch and 1/2-inch thick compact tension specimens and the double cantilever beam (DCB) specimen shown in Figure 4. Crack orientations were always in the transverse grain direction with loading in the longitudinal grain direction.

SECTION III

TEST PROCEDURES

Tensile and fracture toughness tests were performed on a Wiedemann tensile testing machine according to ASTM Standards at room, $200^{\circ}F$, $0^{\circ}F$, and $-65^{\circ}F$ temperatures. Testing at $0^{\circ}F$ and $-65^{\circ}F$ was accomplished in a styrofoam test chamber with dry ice as the cooling agent. A split three-zoned Marshall furnace was employed to test at $200^{\circ}F$.

Constant amplitude fatigue crack growth studies were performed on a closed-loop MTS hydraulic testing system. All cyclic loading wave forms were sinusoidal. Fatigue crack growth was monitored optically on the specimen surface with a 35 X Gaertner microscope. After the specimen failed, the observed crack length was then corrected for the internal curvature of the crack front. A Conrad-Missimer test chamber was utilized for the $-65^{\circ}F$, $0^{\circ}F$, $200^{\circ}F$, and $350^{\circ}F$ fatigue crack growth tests. One crack growth specimen was tested at each temperature except for $0^{\circ}F$. A duplicate test was conducted at $0^{\circ}F$ in order to establish the repeatability of the crack growth results.

SECTION IV

RESULTS AND DISCUSSION

The tensile properties developed for the 7175-T736 forging are presented in Table I. The room temperature tensile values are slightly less than those of 7075-T651 for 11/16 x 16-inch ribbed extrusion presented in Reference 2.

Fracture toughness properties of the 7175-T736 forging are shown in Table II. Although fracture toughness specimens were tested in the longitudinal (LW) direction, all LW data was invalid by ASTM E399 criteria due to the irregular crack front curvatures (Figure 5) obtained when precracking the specimens. This data is not included in Table II. These irregular crack fronts were probably due to anisotropic material properties in the forging, as a specimen rejection of this size because of crooked crack fronts is extremely rare.

Comparable toughness data was generated in the other investigations for several high strength aluminum alloys as shown in Table III. A quick look at Table III reveals a wide range in both yield strength and toughness for the 7075. All the data is for wrought products. It would then be desirable to base a toughness comparison to 7075 products that have yield strength values close to that of the 7175. The first and most obvious comparison would be to the 2 x 8-inch hand forging. However, this comparison is not acceptable because of the lack of short transverse data. Therefore, a comparison to the 3-1/2 x 7-1/2-inch extrusion data is acceptable. In this comparison the 7175 is seen to be significantly superior in the short transverse (TW) direction and slightly better in the transverse (WL) direction.

TABLE I

TENSILE PROPERTIES OF 7175-T736 ALUMINUM ALLOY FORGING

Number of Tests	Temperature (° F)	Direction	Ultimate Strength KSI	Yield Strength KSI	Elong. in 1" G. L. (%)	Reduction of Area (%)
3	-65	Longitudinal	85.1	78.1	11.7	28.8
3	0	"	83.2	76.0	12.4	34.0
3	R. T.	"	81.2	74.6	12.2	37.5
3	200	"	70.2	65.5	14.6	44.9
2	-65	Transverse	78.6	68.6	7.2	9.6
3	0	"	75.1	65.2	8.0	17.0
3	R. T.	"	74.5	66.3	9.3	22.3
3	200	"	64.0	61.7	10.2	32.7
3	-65	Short	76.8	66.6	6.6	9.9
3	0	Transverse	75.6	65.9	7.4	13.0
3	R. T.	"	73.6	64.9	7.8	15.6
3	200	"	64.0	60.5	9.6	26.2

TABLE II

FRACTURE TOUGHNESS PROPERTIES OF
7175-T736 ALUMINUM ALLOY FORGING

Temperature	Direction	K_{IC} (KSI $\sqrt{IN}$)
Room	Transverse (WL)	22.7
		23.4*
		23.8*
Room	Short Transverse (TW)	33.1
		29.1
		33.5
		31.9 Avg.
$200^{\circ}F$	"	33.0
		35.0
		34.4
		34.1 Avg.
$0^{\circ}F$	"	26.4
		27.1
		26.3
		26.6 Avg.
$-65^{\circ}F$	"	26.0
		26.7
		26.1
		26.3 Avg.

* Invalid test; crack length does not meet ASTM standards.

TABLE III

TYPICAL ROOM TEMPERATURE FRACTURE TOUGHNESS PROPERTIES FOR SEVERAL HIGH STRENGTH ALUMINUM ALLOYS

Alloy and Temper	Configuration	Cross Sectional Configuration (in x in)	Direction					
			Longitudinal		Transverse		Sh. Transverse	
			YS (KSI)	K_{IC} (KSI IN)	YS (KSI)	K_{IC} (KSI IN)	YS (KSI)	K_{IC} (KSI IN)
7075-T7352 (ref. 3)	Hand Forging	2 x 8	65.8	31.4	65.3	24.0	-	-
7075-T7352 (ref. 3)	Hand Forging	6 x 24	50.7	39.5	48.9	27.7	47.2	25.6
7075-T651 (ref. 4)	Plate	1 x 20	78.0	30.6	75.0	27.8	-	-
7075-T7351 (ref. 4)	Plate	1 x 20	62.0	35.3	59.0	31.1	-	-
7075-T6511 (ref. 5)	Extrusion	3-1/2 x 7-1/2	74.7	30.9	67.2	20.8	-	19.0
7175-T73	Die Forging	2-1/2 x 2-1/2	74.6	-	66.3	22.7	64.9	31.9

(References are listed in Section VI.)

The transverse fatigue crack growth properties of the 7175 forging at room temperature are presented in Figure 6. The crack growth data generated in this program at room temperature compares favorably with 7075-T6 and 7075-T736 crack growth data published in References 3 and 6, respectively.

A frequency change from 60 cpm to 120 cpm had very little effect on the crack growth behavior. However, an "R" ratio (ratio of minimum fatigue load to maximum fatigue load) change from 0.1 to 0.5 produced an increase in crack growth rate. This is to be expected since the maximum stress intensity is higher for the larger "R" ratio.

Fatigue crack growth data at 350°F, 200°F, and room temperature are shown in Figure 7. The elevated test temperatures increased the crack growth rate of 7175-T736. Fatigue crack growth data at -65°F, 0°F, and room temperature are shown in Figure 8. Observation of the results shown in Figure 8 would tend to indicate that (relative to room temperature) the growth rate increased at 0°F and decreased at -65°F. However, these apparent trends are probably caused by normal scatter in the test data and are not considered real, particularly as only one specimen was tested at room temperature and -65°F, and only two specimens at 0°F. This scatter could be attributed to humidity variations, since humidity was neither controlled nor monitored, leading to varying amounts of frost and ice condensing at the crack tip at low temperatures. The above speculation connotes that although 7175-T736 is not particularly sensitive to cracking in a corrosive environment when statically loaded, it may be environment-sensitive while fatigue cracking at low temperatures. Further testing is necessary to establish this fact.

Wei (Reference 7) has suggested that fatigue crack growth under the influence of low or elevated temperatures may behave according to an Arrhenius-type rate process as presented in the following equation:

$$da/dN = A\ f(\Delta K)\ \exp\left\{\frac{-u\ (\Delta K)}{kT}\right\}$$

where

A = a constant

$f(\Delta K)$ = a stress intensity function

$u(\Delta K)$ = apparent activation energy as a function of stress intensity

k = Boltzmann's constant

T = absolute temperature

Wei also presented data to verify this equation for 7075-T651 in a distilled water environment from temperatures of 180°F to 32°F. Johnson and Wilner (Reference 8) hawe presented H-11 steel alloy data in distilled water environment from temperatures of 180°F to 32°F which agrees with this equation. The Arrhenius-type of correlation would fit the elevated and room temperature data presented in this report (see Figure 9), but when considering the 0°F and -65°F crack growth data the Wei relationship is no longer valid for predicting the results. It is essential that environmental influences as well as the loading parameters should remain constant for successful application of the Wei rate process equation.

The grain directions in the forging coincided with the physical directions of the forging at the center section as shown by photomicrographs in Figure 10.

SECTION V
CONCLUSIONS

The 7175-T736 alloy has previously been shown to have superior fracture toughness and stress corrosion properties (see appendix). A comparison to 7075 at comparable yield strength confirmed that the fracture toughness properties of 7175 did exceed the 7075 toughness in the short transverse and transverse directions. A homogenization of the transverse and short transverse toughness properties would certainly be desirable.

Room temperature fatigue crack growth properties were essentially the same for both the 7175 and 7075 alloys. Crack growth rates at elevated temperatures were faster than the room temperature crack growth rate. The Wei rate process equation was observed to fit the elevated and room temperature crack growth data. At lower temperatures, variations in testing environment apparently influenced the crack growth rate and a definite trend was not established.

Figure 1. Test Section of 7175-T736 Aluminum Die Forging

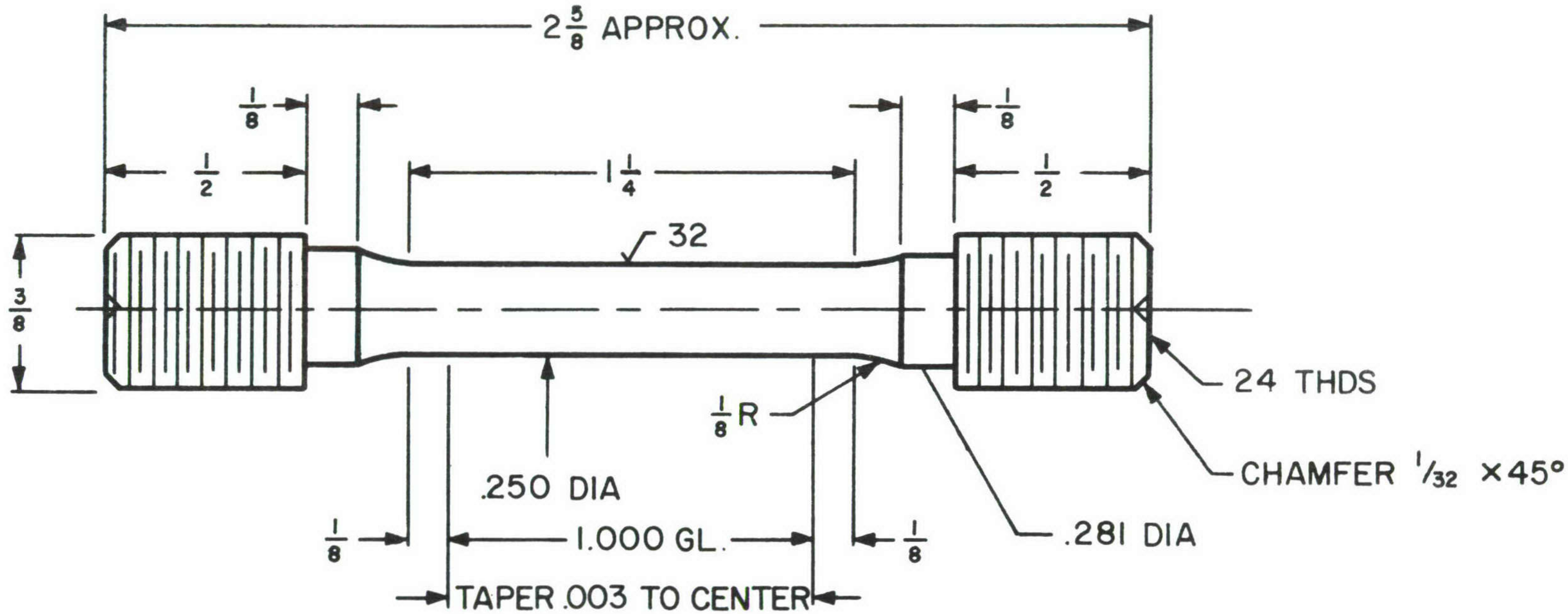
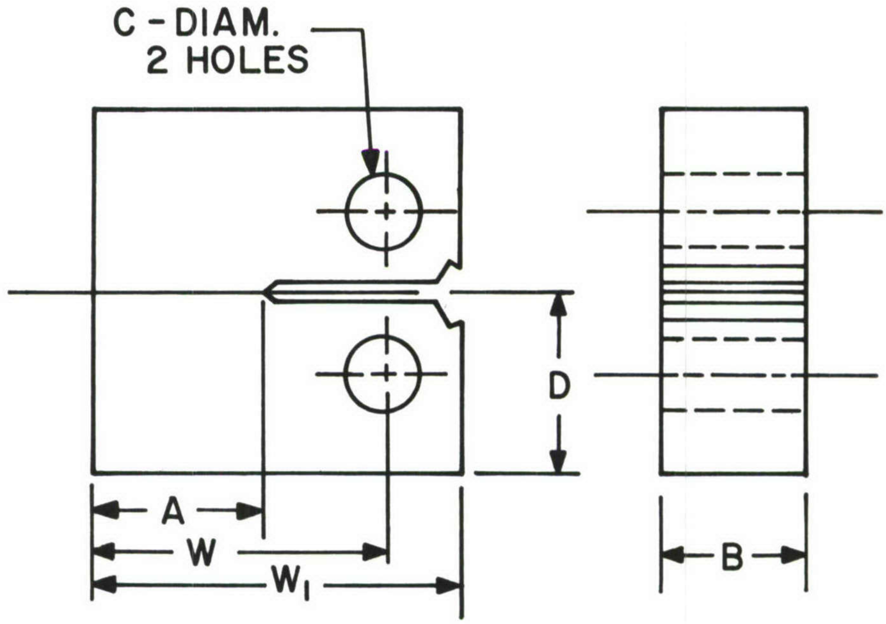


Figure 2. Tensile Specimen Configuration



DIMENSIONS

SPECIMEN THICKNESS (INCHES)	A	B	W	W_1	D	C
1	1.100	1.000	2.000	2.500	1.200	0.500
3/4	0.835	0.750	1.500	1.875	0.900	0.375
1/2	0.550	0.500	1.000	1.250	0.600	0.250

Figure 3. Fracture Toughness Compact Tension Specimen Configuration

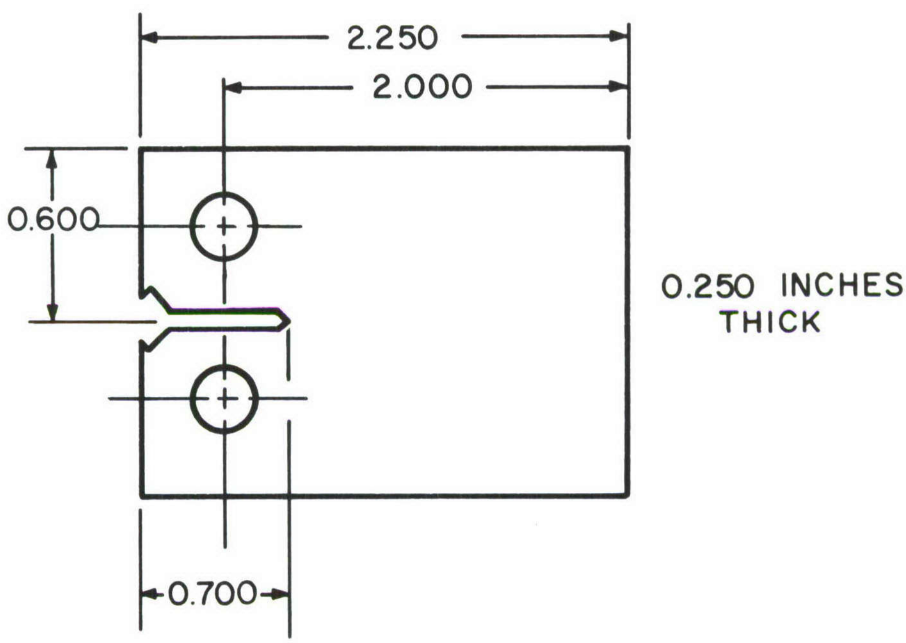


Figure 4. DCB Crack Growth Specimen Configuration

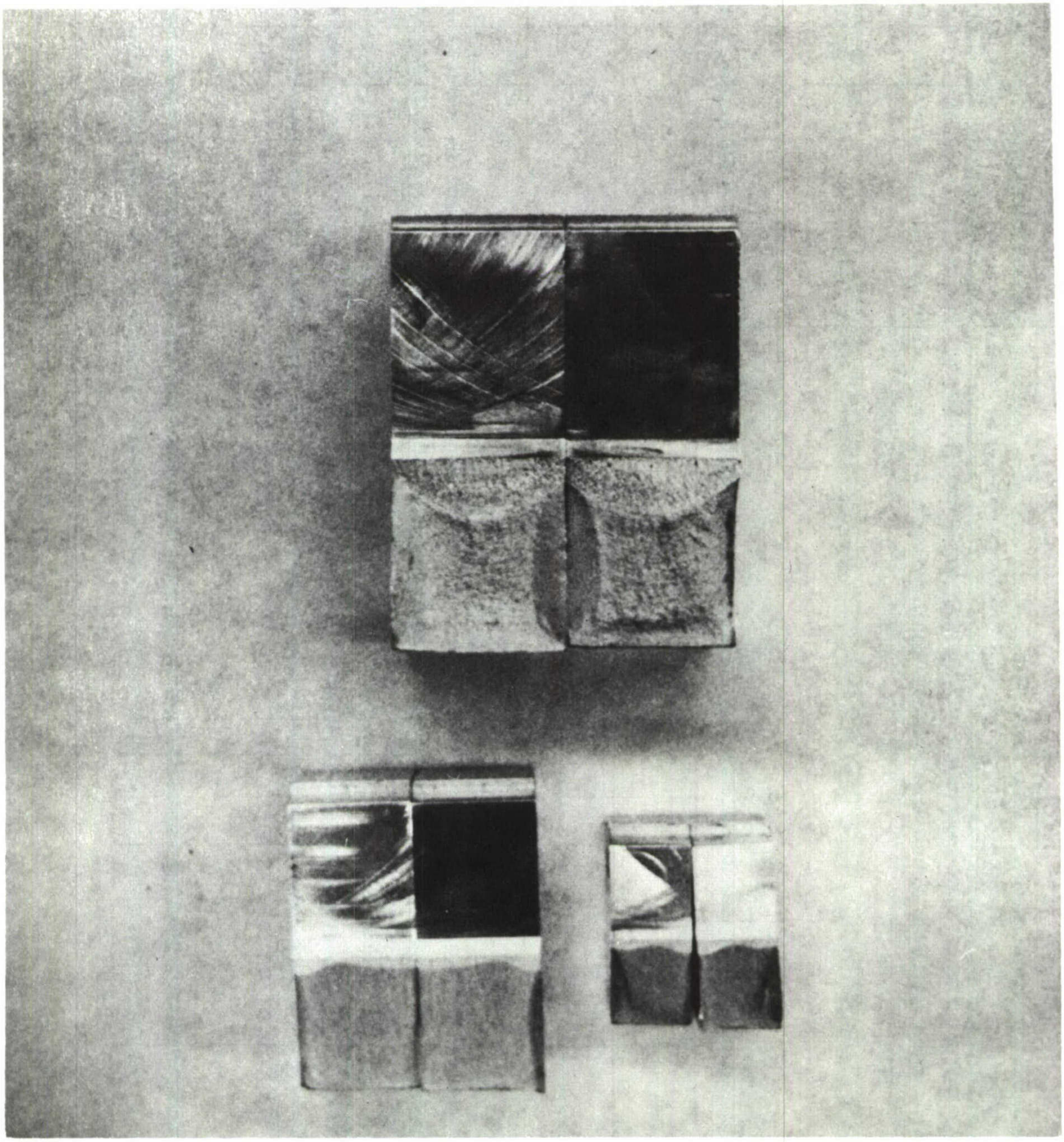


Figure 5. Irregular Crack Front Curvatures Obtained When Precracking Longitudinal Specimens

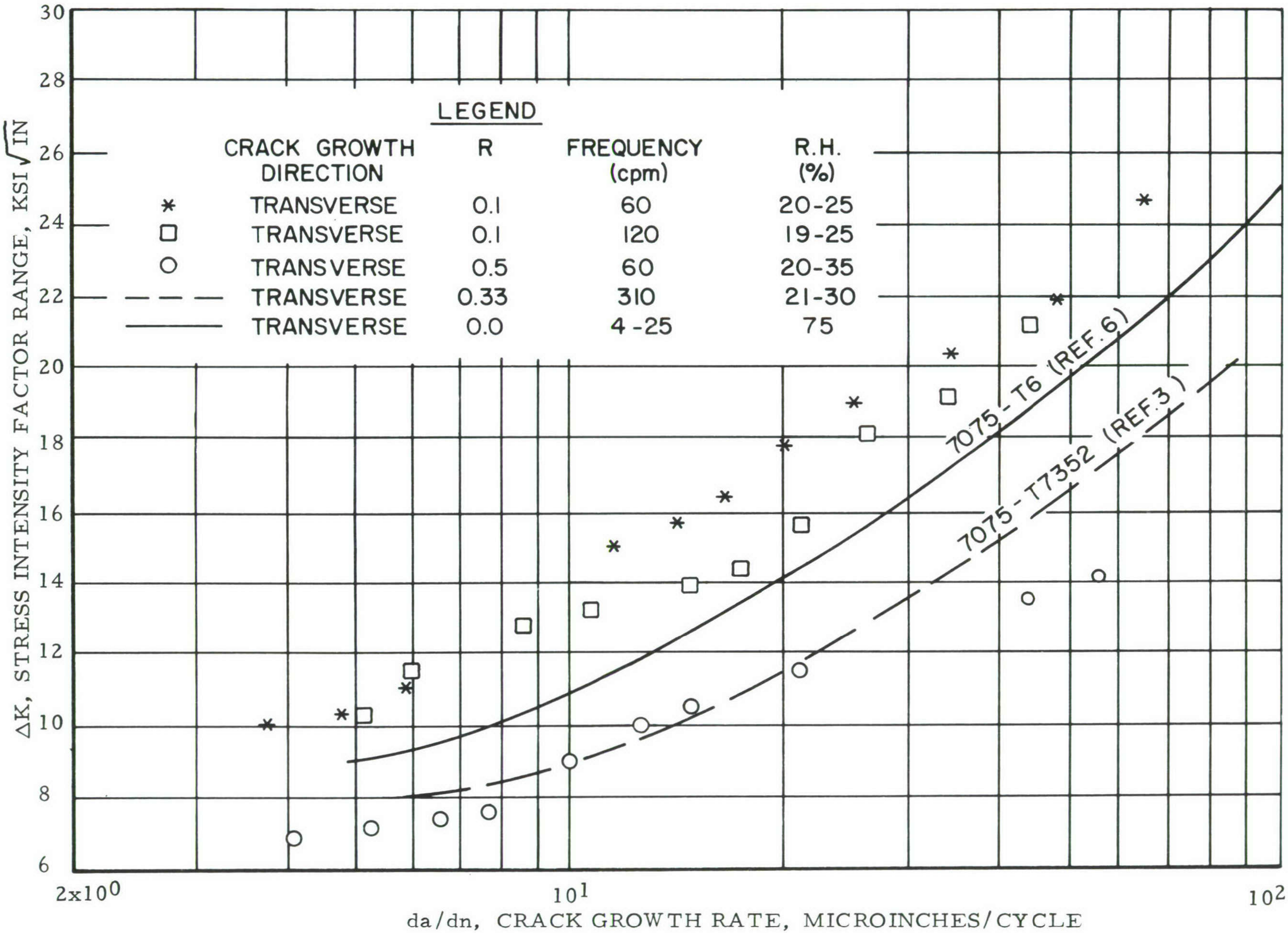


Figure 6. Stress Intensity Factor Range Versus Crack Growth Rate for 7175-T736 Forging at Room Temperature

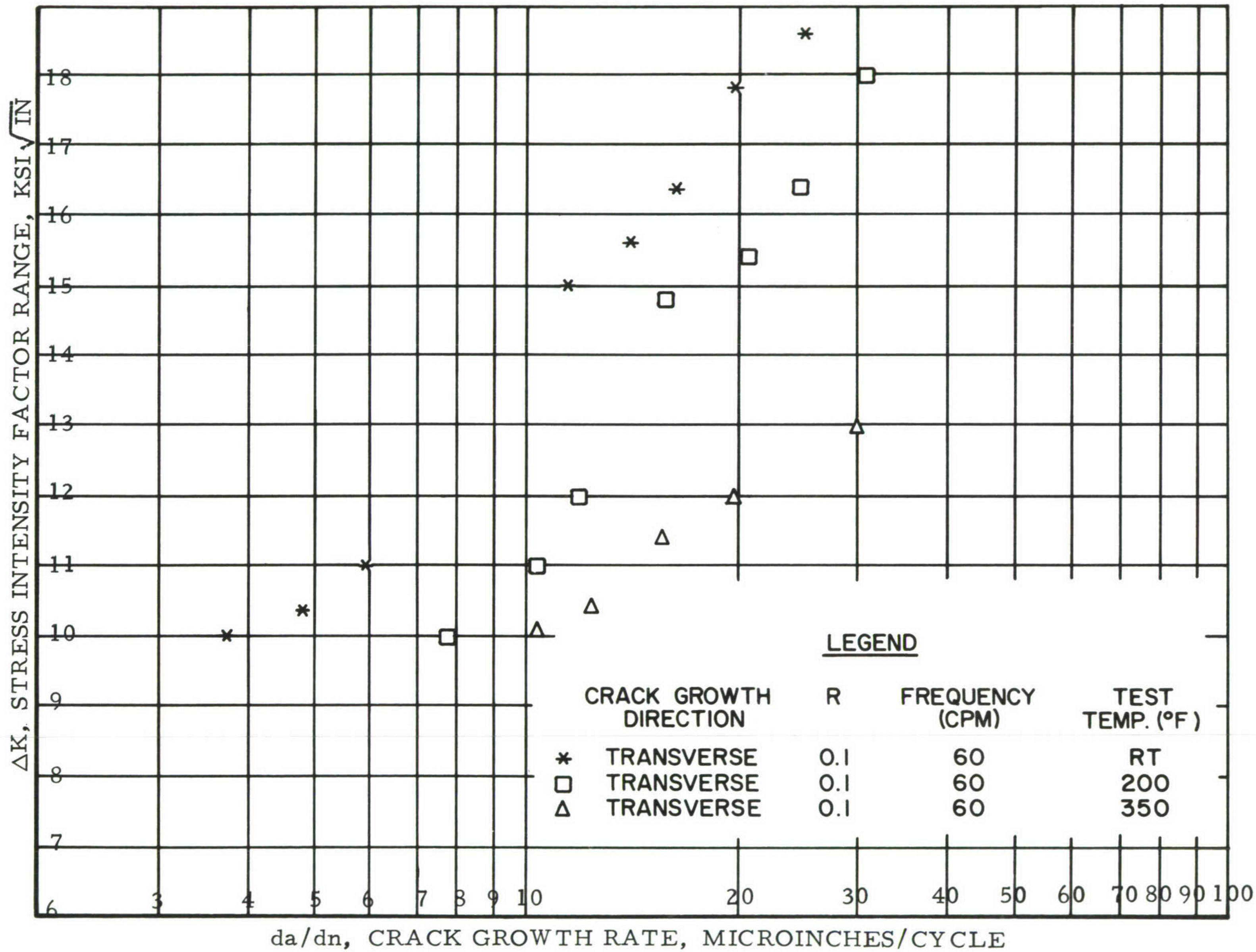


Figure 7. Stress Intensity Factor Range Versus Crack Growth Rate for 7175-T736 Forging at Elevated Temperatures, Compared With Room Temperature

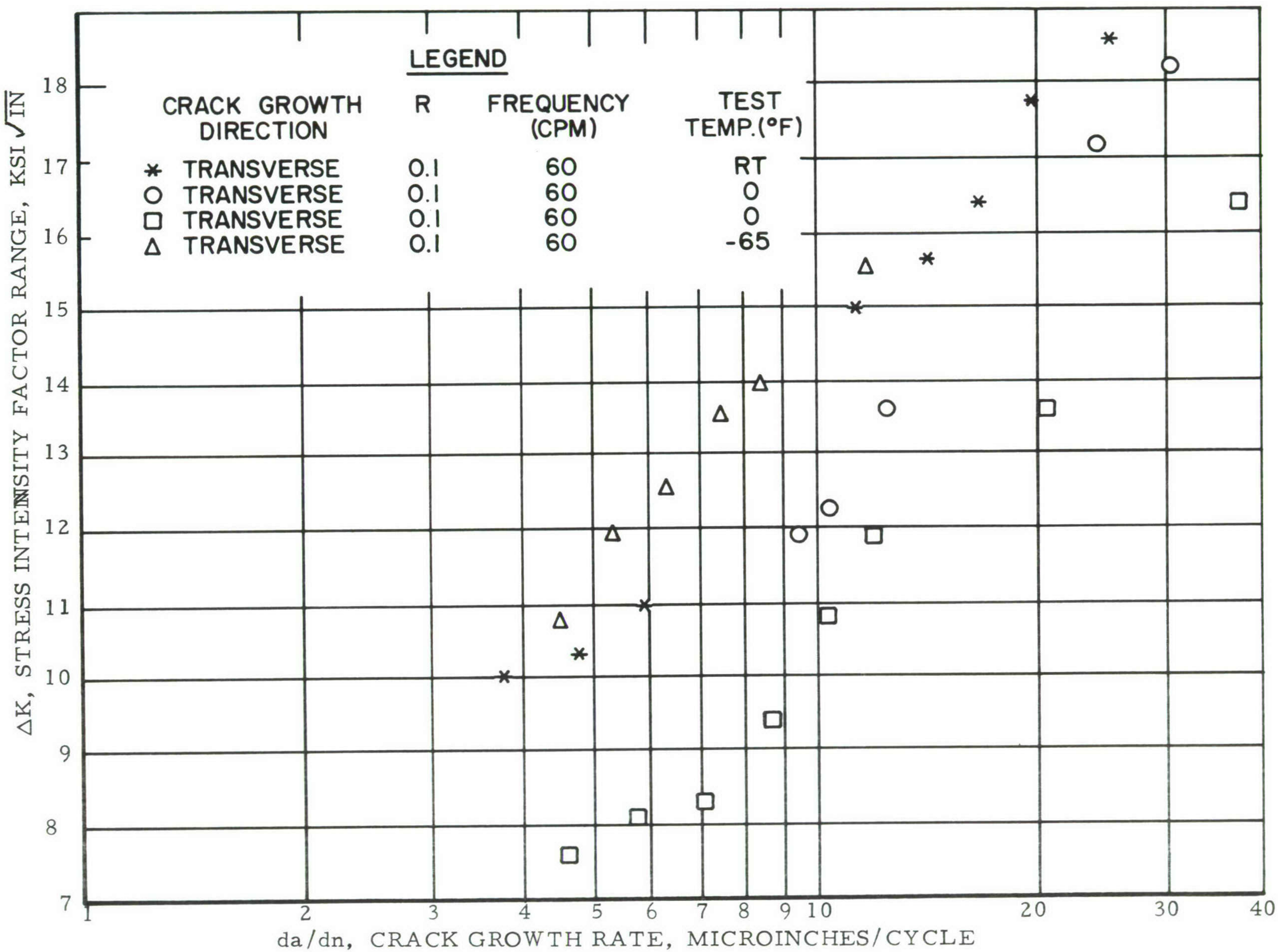


Figure 8. Stress Intensity Factor Range Versus Crack Growth Rate for 7175-T736 Forging at Low Temperatures, Compared With Room Temperature

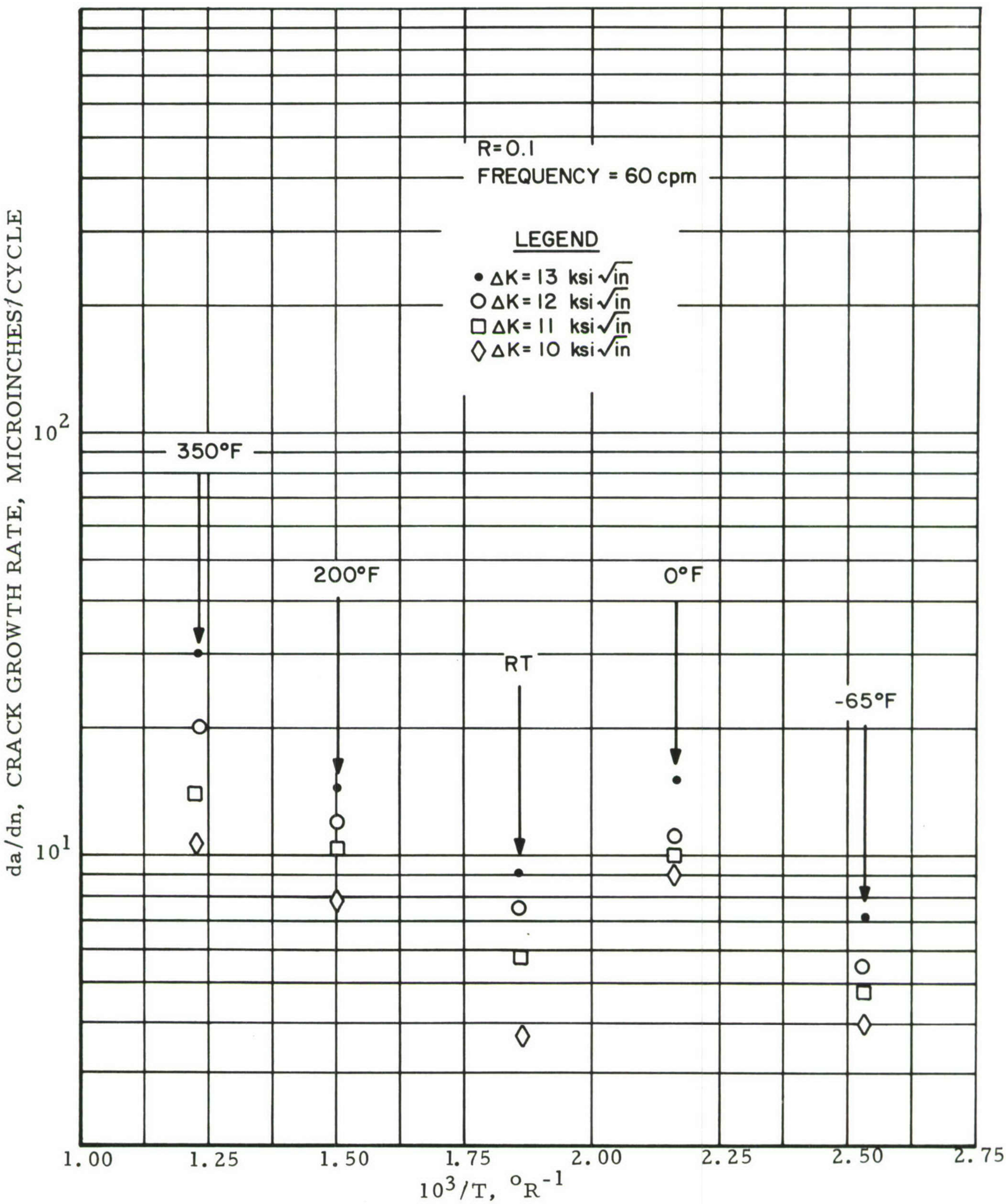


Figure 9. Fatigue Crack Growth Rate Versus the Reciprocal of Test Temperature for 7175-T736 Forging

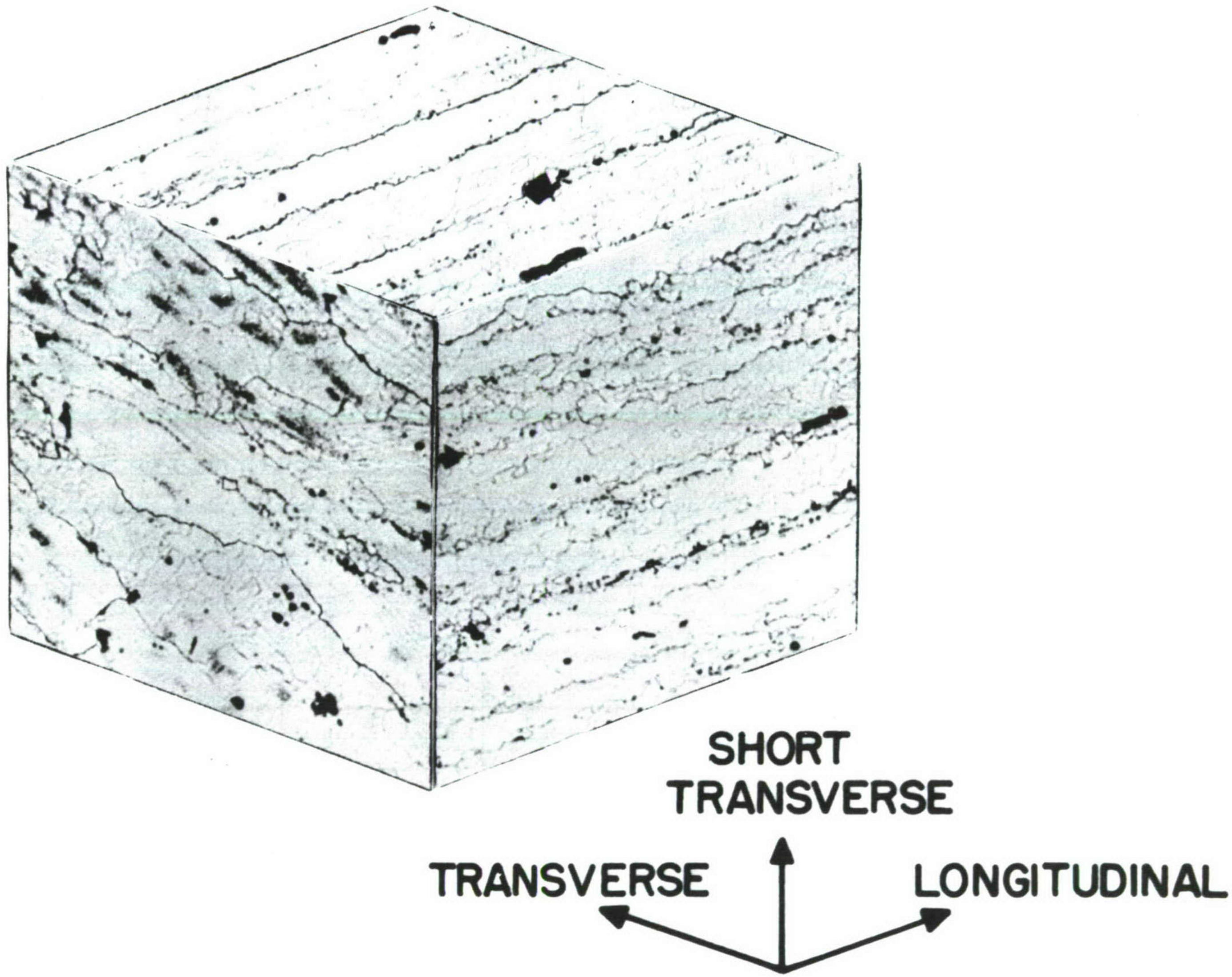


Figure 10. Microstructure at Center of 7175-T736 Aluminum Alloy Forging (500X)

SECTION VII

APPENDIX

The following are data extracted from Reference 1. For specimen sizes, forging configurations, and testing procedures associated with these data, refer to University of Dayton Research Institute Data Report No. UDRI-DR-69-01.

Care must be taken when comparing data from this appendix with data in the main text of this report, since a bar forging was tested in the main report and a squat forging with a flange and web configuration was tested in Reference 1 (see figure on following page).

Alternately immersed smooth specimens were subjected to loads equivalent to 75 percent of the ultimate strength or 75 percent of the yield strength in the referenced report. These specimens survived for 90 days without failure before test termination.

Complicated grain orientations necessitate that only physical directions in the forging and not grain orientation be utilized when indicating specimen locations in the squat forging.

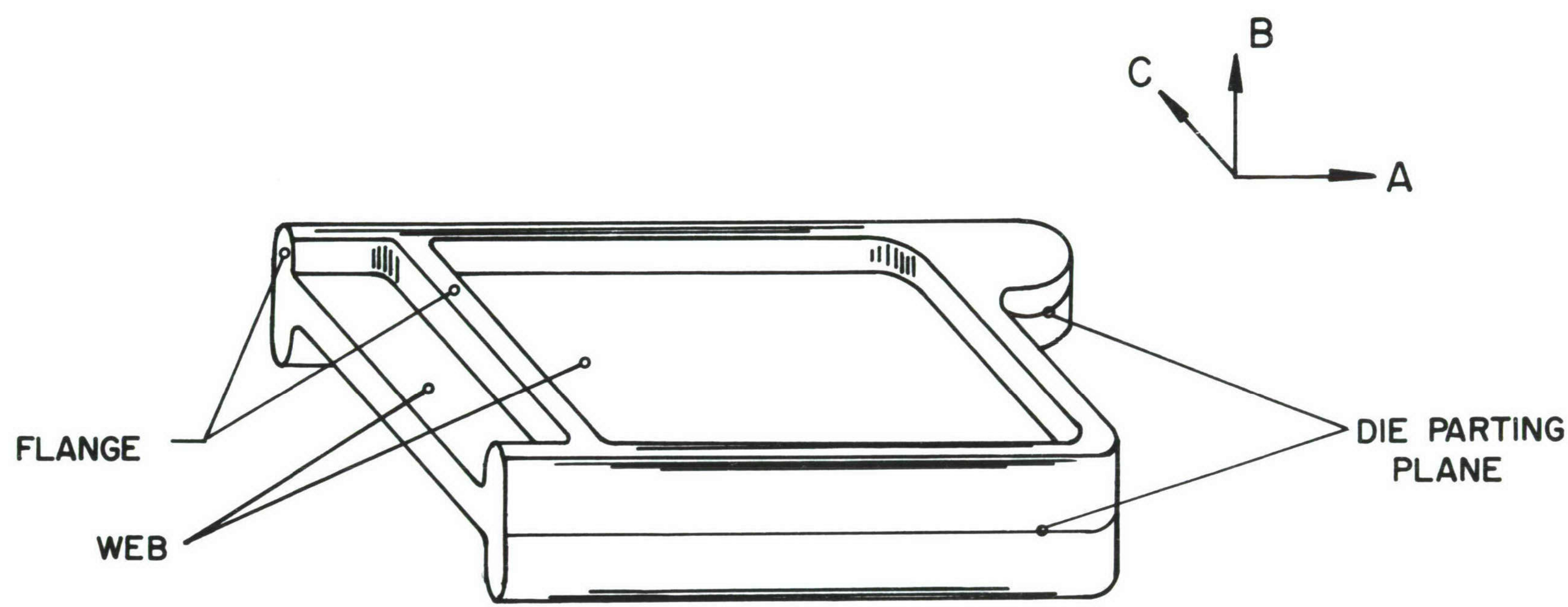


Figure 11.   Forging Configuration Used in Reference 1

TABLE IV

TENSILE PROPERTIES OF 7175-T736 ALUMINUM ALLOY FORGING AS REPORTED IN REFERENCE 1

Number of Tests	Temperature (^{o}F)	Location in Forging	Ultimate Strength KSI	Yield Strength KSI	Elongation in 1" G. L. (%)
3	R. T.	Short Transverse Direction in Flange	73.2	65.5	12.3
3	R. T.	Longitudinal Direction in Flange	79.9	71.4	13.1
3	R. T.	Longitudinal Direction in Web	82.9	75.4	12.6

TABLE V

NOTCHED BEND FRACTURE TOUGHNESS PROPERTIES OF 7175-T736 ALUMINUM ALLOY FORGING AT ROOM TEMPERATURE AS REPORTED IN REFERENCE 1

K_{IC} KSI $\sqrt{in}$	Location in Forging**
28.8*	(a) Longitudinal (A) (b) Web - Parting Line Plane (AC)
36.1*	(a) Short Transverse (B) (b) Flange (BC)
37.8*	(a) Short Transverse (B) (b) Flange (BC)
35.3*	(a) Short Transverse (B) (b) Flange (BA)
33.7*	(a) Longitudinal (A) (b) Web (CA)
36.2*	(a) Longitudinal (A) (b) Web (CA)

* ASTM specimen thickness or crack length criteria violated.

** (a) and (b) signify the following:

(a) Cracking direction

(b) Plane in which crack is oriented

A, B, and C signify axis orientations for forging configuration as shown in Figure 11.

TABLE VI

COMPACT TENSION FRACTURE TOUGHNESS PROPERTIES OF 7175-T736 ALUMINUM ALLOY FORGING AT ROOM TEMPERATURE AS REPORTED IN REFERENCE 1

K_{IC} (KSI$\sqrt{in}$)	Location in Forging
26.0	(a) Longitudinal (A) (b) Flange (AC)
33.1	(a) Longitudinal (A) (b) Web (AB)
35.1*	(a) Transverse (C) (b) Web (BC)
41.7*	(a) Short Transverse (B) (b) Flange-Parting Line Region (BC)
27.7	(a) Transverse (C) (b) Web-Parting Line Plane (AC)
25.2	(a) Transverse (C) (b) Web-Parting Line Plane (AC)
29.6**	(a) Longitudinal (A) (b) Web-Parting Line Plane (AC)
28.1	(a) Longitudinal (A) (b) Web -Parting Line Plane (AC)

* Specimen violated ASTM thickness criteria

** ASTM crack length criteria violated

(a) and (b), A, B, and C - See footnote, Table V, for explanation

TABLE VII

RESULTS OF COMPACT TENSION STRESS CORROSION TESTS
AS REPORTED IN REFERENCE 1

Location in Forging	Load Initial (KIP)	Time Initial	No. of Changes of Load and Environment	Load Final (KIP)	Time Final	K Final (KSI IN)
(a) Longitudinal(A) (b) Flange (AC)	1.12	16:00 22 May 69	3	1.32	12:30 28 May 69	29*
(a) Longitudinal(A) (b) Web (AB)	0.38	16:45 7 Oct 68	17	1.42	08:15 25 Nov 68	43*
(a) Transverse(C) (b) Web (CB)	1.50	09:00 27 Nov 68	15	2.54	10:30 15 May 69	44**

* Failed during changing of environment and increasing of load.

** Grip failure (specimen did not fail in the corrosive environment). Specimen was removed from creep machine and loaded to failure in an Instron tensile machine. An approximate K_Q of 51 KSI$\sqrt{\text{in}}$ was obtained. This K_Q violates thickness criteria. The high K_Q can be explained by an examination of the fracture face. At the leading edge of the crack, delamination of the specimen on planes parallel to the applied load was occurring. The readily observable delaminations extended approximately 1/10 inch into the unbroken ligament. This condition made the entire crack front into a plane stress condition.

(a) and (b), A, B, and C - see Footnote, Table V, for explanation.

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13. ABSTRACT

Tensile, fracture toughness, and crack growth properties of a 7175-T736 aluminum alloy forging were investigated at various temperatures from -65°F to 350°F. Room temperature tensile and fracture toughness data was compared to similar properties for wrought 7075 products. The 7175 appears to be a better alloy. Fatigue crack growth rates at room temperature were similar to 7075-T6 and 7075-T7352 crack growth data in the literature. Crack growth rates increased with increasing temperature from room temperature to 350°F. Crack growth rates below room temperature were probably affected by humidity variations causing condensation of moisture at the crack tip and results were inconsistent.

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7175-T736						
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FATIGUE CRACK GROWTH						

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